REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
19 July 1995

3. REPORT TYPE AND DATES COVERED

4. TITLE AND SUBTITLE
Topics in Synthetic Aperture Radar and Sparse Filter Design

5. FUNDING NUMBERS

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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

U.S. Army Research Office
P.O. Box 12211
Research Triangle Park, NC 27709-2211

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
The views, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other documentation.

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This report summarizes the outcome of research conducted over a three-year period. Part of the research involved optimizing tap weights for sparse FIR filter design, where some tap weights are zeroed either due to failure or by design. Other research dealt with applying polar-format SAR algorithms to radar astronomy, based on a tomographic viewpoint. The main focus of these studies was to extend 2-D SAR techniques to be useful in more general 3-D scenarios.

19951006 003

14. SUBJECT TERMS
Synthetic Aperture Radar (SAR), radar astronomy, beamforming, spectral estimation, sparse filter design

15. NUMBER OF PAGES
4

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

TOPICS IN SYNTHETIC APERTURE RADAR AND SPARSE FILTER DESIGN

FINAL REPORT

Jennifer L.H. Webb

18 July 1995

U. S. Army Research Office

Contract No. DAAL03-92-G-0139

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1 PROBLEM STATEMENT

This report summarizes the outcome of research conducted over a three-year period. Several problems, not all related, were studied during this time.

The first problem considered involved determining how to compensate for failed elements in FIR filters or beamformers, by adjusting the operational multipliers in the system. It was assumed that a failure causes one or more multiplying coefficients to be zeroed. Reconfiguring of the operational coefficients can lead to graceful degradation, and in some case, postpone the replacement of hardware.

At times, it may be desirable to eliminate hardware in the design phase, in order to reduce costs. This second study involved determining which coefficients should be eliminated and under what circumstances, followed by application of the design approach used in the previous study.

As these studies reached a logical conclusion, we gained access to radar data collected by Arecibo Observatory, and started a new study in the area of image formation. Our objective was to produce high-quality images of the Moon's surface, by applying polar-format synthetic aperture radar (SAR) processing to radar-astronomy data. Another high-quality SAR algorithm had been recently applied to the same data with good results, but the polar-format algorithm required significantly less computation, due to some simplifying assumptions. To our knowledge, this was the first application of this algorithm to radar-astronomy data.

As an extension of the Lunar imaging study, we began to study how 2-D SAR algorithms might be used to image nonplanar surfaces with data collected from various viewing positions. The motivation was to improve image quality for scenarios, such as with radar astronomy or military applications, where it may be necessary to deviate from an ideal 2-D data-collection flight path.

A fifth study was motivated by the problem of imaging asteroids. Conventional 2-D range-Doppler techniques are inadequate, because enough of the 3-D surface is illuminated to require a 3-D representation of the data. Unlike the usual SAR imaging scenario, a range-Doppler measurement may be associated with multiple physical locations on the surface of the asteroid. Our objective was to find a method for resolving these scattering components and producing a 3-D rendering.

2 SUMMARY OF RESULTS

For the case where multiplying (amplifying) coefficients may fail, in either direct-form FIR filters or beamformers, we adjusted the operational coefficients by minimizing the peak weighted error using linear programming (LP). Possible alternatives include zeroing the symmetric element, in order to maintain linear phase, or shortening the length of the filter and using only consecutive operational elements. For beamformers or narrowband lowpass filters, the LP peak stopband level was improved 2-4 dB relative to the other alternatives. For lowpass filters with moderately wide passbands, up to 20 dB of improvement could be obtained.

In some cases, it is possible to reduce the hardware cost of an FIR filter if some of the multipliers can be eliminated. We developed two new methods for designing sparse FIR filters, one for cascaded structures, and one for direct-form structures. The cascaded design methodology was based on the observation that periodically occurring transfer-function zeroes could be implemented with sparse

sections, and is most useful for narrowband filters. The direct-form approach applies for certain filters with moderately wide passbands.

In the third study, we applied polar-format spotlight-mode SAR to radar-astronomy data for the first time. The improvement relative to conventional range-Doppler SAR was significant, and resulted in a threefold increase in computational cost. Relative to a high-quality focused range-Doppler approach, we reduced the amount of computation by a factor of 30. A very slight degradation in image quality was due to 2-D algorithm assumptions where a 3-D formulation would be more precise. Polar-format SAR was found to offer a good compromise between computational complexity and image quality.

We went on to investigate how 2-D SAR images might be corrected to compensate for violations of the 2-D algorithm assumptions. A correction algorithm was developed and investigated, and was found to work best for imaging point scatterers or for piecewise-coplanar data-collection positions. When imaging extended targets with data collected from more arbitrary positions, the correction algorithm did not adequately compensate for phase errors; a more complex 3-D SAR model is required for those cases.

Finally, we considered the problem of imaging asteroids. Although a 3-D SAR algorithm could be used to form a full 3-D image, it requires more data and processing than are feasible at present. Assuming that all nonzero reflectivity is concentrated on the surface of the asteroid, it is possible to compute the nonzero reflectivities using a smaller data set. We formulated the problem such that it could be solved using spectral-estimation techniques. At this time, we know of no other proposed solutions.

3 LIST OF PUBLICATIONS

The following either have been published or have been submitted for publication.

1. "Reduced-Rate Block Trunction Coding of Images Using Error Diffusion," by Jennifer L. H. Webb and David C. Munson, Jr., published in IEEE Signal Processing Letters, April 1995.

2. "Chebyshev Optimization of Sparse FIR Filters Using Linear Programming with and Application to Beamforming," by Jennifer L. H. Webb and David C. Munson, Jr., submitted to IEEE Transactions on Signal Processing.

3. "A New Approach to Designing Computationally Efficient Interpolated FIR Filters," by Jennifer L. H. Webb and David C. Munson, Jr., submitted to IEEE Transactions on Signal Processing.

4. "High-Resolution Planetary Imaging via Spotlight-Mode Synthetic Aperture Radar," by Jennifer L. H. Webb and David C. Munson, Jr., submitted to IEEE Transactions on Image Processing.

5. Tapping Space and Spacing Taps: Topics in Radar-Astronomy Imaging and Sparse Filter Design, by Jennifer Lois Harmon Webb, Ph. D. Thesis published by University Microfilms, Inc.

Other than 1), a complete account of all research is given in 5). Conference papers were also written, most of which have been updated and submitted for publication in journals. The conference papers are listed below.

1. "Chebyshev Optimization of Beamformers and FIR Filters Having Failed Elements," by Jennifer H. Webb and David C. Munson, Jr., published in Proceedings of the IEEE International Symposium on Circuits and Systems, May 10-13, 1992, San Diego, CA.

2. "Design of Sparse FIR Filters Using Linear Programming," by Jennifer H. Webb and David C. Munson, Jr., published in Proceedings of the IEEE International Symposium on Circuits and Systems, May 3-6, 1993, Chicago, IL.

3. "High-Resolution Planetary Imaging Via Spotlight-Mode Synthetic Aperture Radar," by Jennifer L. H. Webb, David C. Munson, Jr., and Nick J. S. Stacy, published in Proceedings of the IEEE International Conference on Image Processing, November 13-16, 1994, Austin, TX.

4. "SAR Image Reconstruction for an Arbitrary Radar Path," by Jennifer L. H. Webb and David C. Munson, Jr., published in Proceedings of the IEEE International Conference on Acoustics, Speech and Signal Processing, May 8-12, 1995, Detroit, MI.

5. "Radar Imaging of Three-Dimensional Surfaces Using Limited Data," by Jennifer L. H. Webb and David C. Munson, Jr., to be published in Proceedings of the IEEE International Conference on Image Processing, October 23-26, 1995, Washington, DC.

A journal-article version of 5) above will be submitted in the near future.

4 LIST OF PERSONNEL

Jennifer L. H. Webb earned a Ph. D. in Electrical Engineering two months after funding for the project ended. David C. Munson, Jr. was her advisor.

5 REPORT OF INVENTIONS

none